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ASSESSMENT OF LAW ENFORCEMENT CHEMICAL, BIOLOGICAL, RADIOLOGICAL, AND NUCLEAR PERSONAL PROTECTIVE EQUIPMENT AUDIBLE SIGNATURE

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The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorizing documents.

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14. ABSTRACT

Tactical law enforcement (LE) officers need to wear commercial chemical, biological, radiological, and nuclear (CBRN) personal protective equipment (PPE) during operations such as clandestine laboratory responses, barricaded CBRN terrorist responses, or downed-officer evacuations under hazardous atmospheric conditions. *Audible signature* refers to the noise a tactical officer or his or her equipment may make that could lead to detection by a threat. Some characteristics of CBRN PPE may increase an officer's audible signature and make stealth operations more challenging or impossible. The goal of this effort was to investigate the audible signature characteristics of multiple LE CBRN PPE ensembles when worn with tactical LE equipment. Multiple statistically significant audible signature differences were found among the CBRN PPE ensembles evaluated.

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PREFACE

The work described in this report was authorized under Project No. 20150/CB2. This work was started in June 2011 and completed in October 2011.

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ASSESSMENT OF LAW ENFORCEMENT CHEMICAL, BIOLOGICAL, RADIOLOGICAL, AND NUCLEAR PERSONAL PROTECTIVE EQUIPMENT AUDIBLE SIGNATURE

1. INTRODUCTION

Tactical law enforcement (LE) officers need to wear commercial chemical, biological, radiological, and nuclear (CBRN) personal protective equipment (PPE) during operations such as clandestine laboratory responses, barricaded CBRN terrorist responses, or downed-officer evacuations under hazardous atmospheric conditions.[1] During those operations that require CBRN PPE, it is imperative that officers be able to perform their missions in a tactical manner as similar as possible to those that are not performed in a CBRN environment. One critical tactical PPE requirement is the minimization of *audible signature*, which refers to the noise a tactical officer or his or her equipment may make that could lead to detection by a threat.

Some characteristics of CBRN PPE may increase an officer's audible signature and make stealth operations more challenging or impossible. For instance, powered air-purifying respirator (PAPR) blowers are noisy and render the mask unusable for stealth tactical operations.[2] Additionally, reports indicate that common level B and C suit materials, such as Tyvek and Tychem, produce noise when personnel are actively moving.[3] The goal of this effort was to investigate the audible-signature characteristics of multiple LE CBRN PPE ensembles when they are worn with tactical LE equipment. This objective assessment should be helpful when ensembles are selected for use in tactical operations and could create an impetus for quieter tactical CBRN PPE designs in the future.

2. METHODS

2.1 Volunteers

Eight male volunteers between the ages of 22 and 37 years (29 ± 5 years; mean ± standard deviation [SD]) participated in this study. The average weight and height of the volunteers were 76.4 ± 8.3 kg and 179.1 ± 7.2 cm, respectively. All volunteers were civilian employees of the U.S. Army Edgewood Chemical Biological Center (ECBC; Aberdeen Proving Ground [APG], MD). All volunteers were healthy and free of coronary risk factors as determined by completion of a health history questionnaire. Each volunteer completed the respirator medical evaluation questionnaire for the Occupational Safety and Health Administration, Regulation 29 Code of Federal Regulations, Section 1910.134, Respiratory Protection, and was cleared for respirator wear and testing by medical personnel from the Kirk U.S. Army Health Center, APG, MD. Volunteers were thoroughly briefed on the nature and purpose of the study, and signed informed consent was obtained from each person upon completion of all volunteer agreement paperwork.

2.2 PPE Ensembles

A total of 28 PPE ensemble variables were assessed. Six CBRN suits were worn by the volunteers during this study: Gentex Rampart (Simpson, PA), Lion MT94 (Dayton, OH), Remploy Frontline SR3 (Merseyside, UK), Blauer (Boston, MA) WZ9435 extended response team (XRT) and WZ9430 major incident response team (MIRT), and the Tychem SL (DuPont; Wilmington, DE). The baseline clothing condition was chosen as the U.S. Army Combat Uniform (ACU) because it was readily available and because it closely represented the uniforms that are typically worn by special weapons and tactics (SWAT) operators during tactical maneuvers.

The Lion, Blauer, and Tychem suits that were assessed during this study used a barrier material technology for CBRN protection. The Remploy suit consisted of a barrier material and a carbon adsorbent layer. The Gentex suit had a carbon adsorbent layer alone. The Lion suit was certified according to the National Fire Protection Association (NFPA) 1994 Class 2 and 1992 standards of protection. Both Blauer suits were NFPA 1994 Class 3 certified. None of the other suits assessed during this study were known to be NFPA certified at the time of this publication.

Testing was conducted with six respiratory protection systems: Avon FM53 air-purifying respirator (APR; Avon Protection Systems; Belcamp, MD), Avon FM53 with the ST-PAPR, Avon FM53 with the ST53 self-contained breathing apparatus (SCBA), Scott AV-3000 APR (Scott Safety; Monroe, NC), Scott AV-3000 with the C420 Plus PAPR, and the Scott Air-Pak SCBA. A control condition, during which no respirator was worn, was conducted with each suit condition. Four tactical LE PPE items were worn with each of the 28 ensemble configurations. These four items were the Gentex advanced combat helmet with an Occ-Dial liner kit, Eclipse releasable body armor vest without level IV plates (BAE Systems; London, UK), W.L. Gore model G9492 over gloves (Newark, DE), and Haix Airpower R2 boots (Lexington, KY). A rubber mock M4 carbine rifle was utilized for all movements except the drop-and-crawl movement. All suit and respirator conditions that were assessed are shown in Table 1. Due to equipment challenges, data for the Scott Air-Pak SCBA, condition #8, was only collected for one research volunteer.

Table 1. Ensemble Combinations

Condition Number	Suit	APR or Facepiece	PAPR	SCBA
1	U.S. Army ACU	n/a	n/a	n/a
2	Gentex Rampart	n/a	n/a	n/a
3	Gentex Rampart	Avon FM53	n/a	n/a
4	Gentex Rampart	Avon FM53	Avon ST-PAPR	n/a
5	Gentex Rampart	Avon FM53	n/a	Avon ST53
6	Gentex Rampart	Scott AV-3000	n/a	n/a
7	Gentex Rampart	Scott AV-3000	Scott C420	n/a
8	Gentex Rampart	Scott AV-3000	n/a	Scott Air-Pak
9	Lion MT94	n/a	n/a	n/a
10	Lion MT94	Avon FM53	n/a	n/a
11	Lion MT94	Avon FM53	Avon ST-PAPR	n/a
12	Lion MT94	Avon FM53	n/a	Avon ST53
13	Remploy Frontline SR3	n/a	n/a	n/a
14	Remploy Frontline SR3	Avon FM53	n/a	n/a
15	Remploy Frontline SR3	Avon FM53	Avon ST-PAPR	n/a
16	Remploy Frontline SR3	Avon FM53	n/a	Avon ST53
17	Blauer WZ9435 XRT	n/a	n/a	n/a
18	Blauer WZ9435 XRT	Avon FM53	n/a	n/a
19	Blauer WZ9435 XRT	Avon FM53	Avon ST- PAPR	n/a
20	Blauer WZ9435 XRT	Avon FM53	n/a	Avon ST53
21	Tychem SL	n/a	n/a	n/a
22	Tychem SL	Avon FM53	n/a	n/a
23	Tychem SL	Avon FM53	Avon ST-PAPR	n/a
24	Tychem SL	Avon FM53	n/a	Avon ST53
25	Blauer WZ9430 MIRT	n/a	n/a	n/a
26	Blauer WZ9430 MIRT	Avon FM53	n/a	n/a
27	Blauer WZ9430 MIRT	Avon FM53	Avon ST-PAPR	n/a
28	Blauer WZ9430 MIRT	Avon FM53	n/a	Avon ST53

n/a: not applicable

2.3 Sound Measurement System

An audible signature was measured using a highly sensitive sound measurement test system as described in detail by Eshbaugh et al. (2010).[4] This test system was designed to comply with MIL-STD-1474D.[5] The system included an anechoic (echo-free) chamber, a free-field microphone with a power supply, a data acquisition device, a closed-circuit television (CC-TV), custom-designed LabVIEW software (National Instruments; Austin, TX), and an intercom to allow communication between the test operator and volunteer. The anechoic chamber was approximately 3 × 3 × 2 m (length × width × height). The free-field microphone (Type 40AF; G.R.A.S. Sound and Vibration; Holte, Denmark) was mounted at a height of 1.2 m in the horizontal middle of one end of the chamber. Two 1 m^2 rubber mats were placed on the opposite

end of the chamber, away from the microphone, to cushion volunteers from the metal grate flooring and to minimize footfall noise against the metal grates. A rectangle was marked on the mat 2 m from the microphone. All volunteer movements were performed within this rectangle. The location of the rectangle allowed enough room for a volunteer to perform simple movements without being obstructed by the anechoic chamber walls and conformed to the recommended measurement distance stated in MIL-STD-1474D.

2.4 Exercise Movements

Three sets of movements (also called exercises) were performed during this effort. The first two sets were completed by all eight volunteers, and the third movement, the drop-and-crawl movement, was completed by only one volunteer. All movements were performed at a minimum distance of 2 m away from the microphone, inside of a 0.61 × 1.83 m (2 × 6 ft) rectangle as shown in Figure 1.

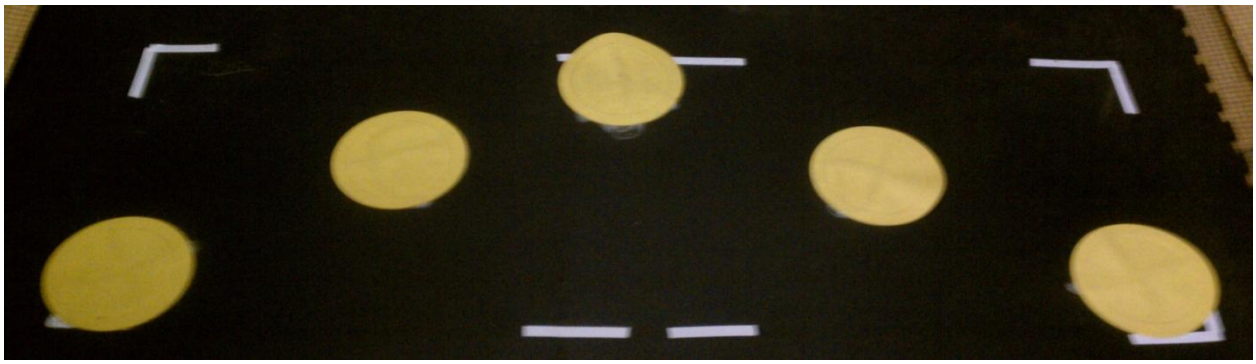

Figure 1. Movement rectangle and arch.

2.4.1 LE Movement Scenarios

Volunteers donned each of the PPE ensembles and performed four movement scenarios by following the arch shown in Figure 1. These scenarios attempted to replicate activities that would be performed by LE personnel. They included simulated door entry, high-knee raise and scan, crouch and rifle scan, and a quick movement. For each scenario, volunteers started at the circle on the far right and faced the back of the chamber, away from the microphone. The exercise ended at the circle on the far left, with the volunteer facing the front of the chamber and the microphone. The movement scenarios were:

1. Simulated door entry: Volunteers took two small steps forward while shouldering a mock M4 carbine rifle. Next, they removed their left hand from the weapon and simulated opening a door. Finally, they simulated peering around a doorway and took two additional small steps forward.

2. High-knee raise and scan: Volunteers took two high-knee steps forward while shouldering a mock M4 carbine rifle. For the high-knee steps, they

raised their thighs so that they were approximately parallel to the floor then lowered their legs. Next, they scanned 90° to their right and left while in a shooting position. Lastly, they took two additional high-knee steps forward.

3. Crouch and rifle scan: Volunteers took two small steps forward while shouldering a mock M4 carbine rifle. Then they crouched and scanned 90° to the right and left. They returned to a standing position and took two additional small steps forward.

4. Quick movement: Volunteers took four steps forward at a fast walking pace while shouldering a mock M4 carbine rifle.

2.4.2 Repeated Movements

In addition to the movements described in Section 2.4.2, volunteers donned each of the PPE ensembles and performed five consecutive repetitions of three exercises. These exercises were performed with the volunteer facing the microphone while standing on the circle at the top, center of the arch shown in Figure 1. These repeated movements were only performed for the PPE ensemble combinations that did not include the respirator (i.e., Table 1; conditions 1, 2, 9, 13, 17, 21, and 25):

1. Stationary high-knee raise: While standing and shouldering a mock M4 carbine rifle, volunteers raised their right leg so that their thigh was parallel to the floor. Then they returned to a standing position and repeated the motion with their left leg.

2. Stationary rifle scan: From a standing firing position, while shouldering a mock M4 carbine rifle, volunteers scanned 90° to their right and left.

3. Stationary crouch: From a standing firing position, while shouldering a mock M4 carbine rifle, volunteers stepped forward as far as possible with their right leg, bent their right knee approximately 90°, and scanned 90° to their right and left. They then returned to a standing firing position.

2.4.3 Drop-and-Crawl Exercise

An additional exercise was added to the study for one volunteer to allow for a comparison between the movements used in this effort and the audible signature test movement prescribed in *CBRN Protective Ensemble Standard for Law Enforcement*, National Institute of Justice (NIJ) Standard-0116.00.[6] For this movement, the volunteer dropped to both knees then went down on his stomach and crawled 0.91 m (3 ft) with elbows, stomach, and knees touching the floor. He then returned to a standing position. One volunteer performed this drop-and-crawl movement while wearing seven of the PPE ensembles. The ensemble combinations (Table 1) included the baseline condition (i.e., condition 1) and when the FM53 APR was worn with each of the six suits (i.e., conditions 3, 10, 14, 18, 22, and 26).

2.5 Test Conditions

The microphone was calibrated at the start of each test session. The calibration value was determined daily by placing a 1000 Hz, 94 dB sound source (Type 4231, Brüel & Kjær; Nærum, Denmark) at the microphone. The calibration value was automatically saved in a file and was used with the data acquisition program.

The operation of the test system for this PPE audible signature testing was straightforward. The volunteer entered the chamber wearing the PPE ensemble condition of interest. With the microphone turned on and the software running, the operator told the volunteer to perform a specific movement. The operator confirmed that the volunteer was performing the appropriate movement by watching the CC-TV. The sound pressure and decibel frequency bands were recorded for a maximum of 30 s then the test was complete. The file for that PPE ensemble and movement was recorded. The operator prompted the volunteer to move on to the next movement or to exit the chamber after completing all movements for that PPE ensemble. When wearing PPE ensembles that did not include a respirator variable, volunteers completed the LE movement scenarios and repeated movements for a total of seven exercises. For the PPE ensemble variables that included a respirator, the volunteers completed only the four LE movement scenarios described in Section 2.4.1.

2.6 Data Analysis

The individual peak sound pressure level (SPL) was calculated for each PPE ensemble and movement combination. Then the mean peak SPL was calculated across all eight volunteers for each PPE ensemble and movement combination. Descriptive statistics were calculated for each of the CBRN PPE ensembles when worn while volunteers performed each of the movements. Analysis of variance (ANOVA) and post-hoc analyses were conducted using SigmaPlot 12.0 (Systat Software Inc.; Chicago, IL) as deemed appropriate.

3. RESULTS

3.1 LE Movement Scenarios

Descriptive statistics were calculated for each of the CBRN PPE ensemble configurations with each LE movement. Tables 3–6 provide the mean peak SPLs. In addition to descriptive statistics, a one-way, repeated-measures, ANOVA on ranks was performed. The ANOVA on ranks was used because the data for each of the four LE movements were not normal. Evaluation of the ANOVA on ranks, performed at the $p = 0.05$ level, showed that significant differences existed between the PPE ensemble variables for each of the four exercises. A Tukey multiple pairwise comparison test was used to determine the specific statistically significant differences between the PPE ensemble variables. The key, shown in Table 2, was used in concert with Tables 3–6 to represent significant differences between the PPE ensemble variables. The values in Tables 3–6 are in units of decibels A-weighting (dBA).

Table 2. PPE Ensemble Pair-Wise Comparison Key

Key	Significantly different from:
a	U.S. Army ACU
b	Gentex Rampart with no mask
c	Gentex Rampart with the Avon FM53 APR
d	Gentex Rampart with the Avon ST-PAPR
e	Gentex Rampart with the Avon ST-53 SCBA
f	Lion MT94 with no mask
g	Lion MT94 with the Avon FM53 APR
h	Lion MT94 with the Avon ST-PAPR
i	Lion MT94 with the Avon ST-53 SCBA
j	Remploy Frontline SR3 with no mask
k	Remploy Frontline SR3 with the Avon FM53 APR
l	Remploy Frontline SR3 with the Avon ST-PAPR
m	Remploy Frontline SR3 with the Avon ST-53 SCBA
n	Blauer WZ9435 XRT with no mask
o	Blauer WZ9435 XRT with the Avon FM53 APR
p	Blauer WZ9435 XRT with the Avon ST-PAPR
q	Blauer WZ9435 XRT with the Avon ST-53 SCBA
r	Tychem SL with no mask
s	Tychem SL with the Avon FM53 APR
t	Tychem SL with the Avon ST-PAPR
u	Tychem SL with the Avon ST-53 SCBA
v	Blauer WZ9430 MIRT with no mask
w	Blauer WZ9430 MIRT with the Avon FM53 APR
x	Blauer WZ9430 MIRT with the Avon ST-PAPR
y	Blauer WZ9430 MIRT with the Avon ST-53 SCBA

Table 3. Mean Peak SPL for the Simulated Door Entry Movement

Suit	No Respirator		FM53		ST PAPR		ST53 SCBA	
	Key*	Mean (SD)	Key*	Mean (SD)	Key*	Mean (SD)	Key*	Mean (SD)
Baseline	n, o, p, q, r, s, t, u	42.16 (3.99)	n/a	n/a	n/a	n/a	n/a	n/a
Blauer WZ9430 MIRT	a, b, j, k	48.91 (3.35)	n/a	48.71 (2.49)	n/a	50.32 (2.61)	n/a	49.25 (2.35)
Blauer WZ9435 XRT	n, o, p, q, r, s, t, u	53.65 (4.87)	a, b	51.45 (3.12)	a, b, j	52.35 (2.26)	a, b, j	53.05 (3.42)
Gentex Rampart	n/a	41.71 (3.31)	r, t	45.38 (4.58)	n/a	47.64 (1.14)	r, t	46.08 (3.12)
Lion MT94	n/a	50.49 (3.59)	n/a	49.89 (2.11)	n/a	49.96 (2.14)	n/a	49.59 (2.23)
Remploy SR3	n, o, q, r, s, t, u	45.24 (2.43)	n, r, t	46.05 (4.85)	n/a	48.30 (2.31)	n/a	47.55 (3.40)
Tychem SL	a, b, c, e, j, k	53.40 (2.05)	a, b, j	52.09 (2.25)	a, b, c, e, j, k	53.23 (2.39)	a, b, j	52.41 (1.56)

* Refer to Table 2 for key definitions.
Note: Values are in A-weighted decibels.
n/a: not applicable

Table 4. Mean Peak SPL for the High-Knee Raise and Scan Movement

Suit	No Respirator		FM53		ST PAPR		ST53 SCBA	
	Key*	Mean (SD)	Key*	Mean (SD)	Key*	Mean (SD)	Key*	Mean (SD)
Baseline	o, n, p, q, r, s, t, u	45.70 (6.16)	n/a	n/a	n/a	n/a	n/a	n/a
Blauer WZ9430 MIRT	n/a	54.63 (2.16)	n/a	54.61 (3.14)	n/a	55.34 (3.13)	n/a	54.86 (2.62)
Blauer WZ9435 XRT	a, c, e	57.51 (3.06)	a	56.43 (3.02)	a, c, e	57.12 (2.90)	a, c, e, k	57.26 (2.32)
Gentex Rampart	r, s, t, u	47.62 (6.80)	n, p, q, r, s, t, u	48.03 (5.59)	r, s, t, u	50.11 (3.38)	n, p, q, r, s, t, u	48.28 (3.70)
Lion MT94		55.13 (2.19)	n/a	54.74 (1.91)	n/a	55.39 (2.21)	n/a	55.51 (2.25)
Remploy SR3	r, s, u	51.06 (4.42)	q, r, s, t, u	49.95 (3.50)		52.39 (3.09)	r, s, t, u	50.91 (3.44)
Tychem SL	a, b, c, d, e, j, k, m	60.90 (4.02)	a, b, c, d, e, j, k, m	60.23 (2.40)	a, b, c, d, e, k, m	59.89 (3.32)	a, b, c, d, e, j, k, m	62.10 (4.73)

* Refer to Table 2 for key definitions.
Note: Values are in A-weighted decibels.
n/a: not applicable

Table 5. Mean Peak SPL for the Crouch and Rifle Scan Movement

Suit	No Respirator		FM53		ST PAPR		ST53 SCBA	
	Key*	Mean (SD)	Key*	Mean (SD)	Key*	Mean (SD)	Key*	Mean (SD)
Baseline	n, p, q, r, s, t, u	43.08 (5.30)	n/a	n/a	n/a	n/a	n/a	n/a
Blauer WZ9430 MIRT	n/a	48.45 (2.28)	n/a	48.94 (2.71)	n/a	49.42 (2.09)	n/a	50.41 (2.31)
Blauer WZ9435 XRT	a, c	52.74 (4.35)	c	52.18 (3.13)	a, c	52.65 (2.79)	a, c	53.05 (3.39)
Gentex Rampart	r, s, t, u	44.33 (6.06)	o, n, p, q, r, s, t, u	43.42 (1.79)	n/a	48.81 (1.69)	r	47.58 (2.71)
Lion MT94	n/a	51.62 (3.99)	n/a	50.25 (2.19)	n/a	50.86 (1.61)	n/a	50.89 (2.78)
Remploy SR3	r, s, t, u	47.21 (2.47)	r, s, t, u	46.74 (3.40)	n/a	48.67 (3.42)	n/a	48.79 (4.30)
Tychem SL	a, b, c, e, j, k	55.17 (3.36)	a, b, c, j, k	53.52 (2.57)	a, b, c, j, k	54.72 (3.97)	a, b, c, j, k	53.72 (2.08)

* Refer to Table 2 for key definitions.
Note: Values are in A-weighted decibels.
n/a: not applicable

Table 6. Mean Peak SPL for the Quick Movement

Suit	No Respirator		FM53		ST PAPR		ST53 SCBA	
	Key*	Mean (SD)	Key*	Mean (SD)	Key*	Mean (SD)	Key*	Mean (SD)
Baseline	f, n, o, p, q, r, t, u	43.39 (3.67)	n/a	n/a	n/a	n/a	n/a	n/a
Blauer WZ9430 MIRT	n/a	50.74 (4.30)	n/a	50.08 (2.59)	n/a	51.53 (1.63)	n/a	51.53 (3.97)
Blauer WZ9435 XRT	a, b, c, d, e, j, k, m	57.50 (3.55)	a, b, c, e, j	55.79 (5.02)	a, b, c, d, e, j, k, m	57.58 (3.19)	a, b, c, d, e, j	56.06 (4.29)
Gentex Rampart	n, o, p, q, r, t, u	46.39 (4.54)	n, o, p, q, r, t, u	44.32 (1.92)	n, p, q, r, t, u	47.82 (1.29)	n, o, p, q, r, t, u	46.55 (3.28)
Lion MT94	a	53.07 (3.59)	n/a	51.10 (2.60)	n/a	52.60 (3.18)	n/a	52.65 (4.21)
Remploy SR3	n, o, p, q, r, t, u	47.41 (4.33)	n, p	48.63 (4.47)	n/a	50.20 (3.91)	n, p	48.92 (3.00)
Tychem SL	a, b, c, d, e, j	55.60 (3.03)	n/a	56.02 (3.35)	a, b, c, d, e, j	55.81 (3.14)	a, b, c, d, e, j	56.00 (3.46)

* Refer to Table 2 for key definitions.
Note: Values are in A-weighted decibels.
n/a: not applicable

3.2 Repeated Movements

In addition to the individual movements, descriptive statistics were calculated for each of the PPE suits when worn by the volunteers while performing each of the repeated movements. Again, the repeated movements were only performed with the PPE ensemble variables in which the respiratory protection system was not worn (i.e., Table 1; conditions 1, 2, 9, 13, 17, 21, and 25). Tables 7–9 outline the mean peak SPLs. Evaluation of a one-way, repeated-measures ANOVA, performed at the $p = 0.05$ level, showed that significant differences existed between PPE ensemble variables for each of the three repeated movements. A Holm-Sidak post-hoc test was used to determine the specific statistically significant differences between the PPE ensemble variables. These differences are also illustrated in Tables 7–9.

Table 7. Mean Peak SPL for the Repeated Crouch Movement

Suit	Comparison Key*	Mean (SD)
Baseline	b, c, e, g	43.34 (2.92)
Blauer WZ9430 MIRT	a, c, e, g	49.12 (2.17)
Blauer WZ9435 XRT	a, b, d, f	53.63 (3.50)
Gentex Rampart	c, e, g	45.40 (4.69)
Lion MT94	a, b, d, f	52.95 (1.75)
Remploy SR3	c, e, g	45.95 (2.02)
Tychem SL	a, b, d, f	55.26 (2.81)

*This item is significantly different from:
a: U.S. Army ACU
b: Blauer WZ9430 MIRT
c: Blauer WZ9435 XRT
d: Gentex Rampart
e: Lion MT94
f: Remploy SR3
g: Tychem SL
Note: Values are in A-weighted decibels.
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Table 8. Mean Peak SPL for the Repeated Knee-Raise Movement

Suit	Comparison Key*	Mean (SD)
Baseline	b, c, e, g	47.78 (5.68)
Blauer WZ9430 MIRT	a, d, f, g	54.08 (1.61)
Blauer WZ9435 XRT	a, d, f, g	56.12 (2.96)
Gentex Rampart	b, c, e, g	48.91 (4.63)
Lion MT94	a, d, f, g	55.48 (1.31)
Remploy SR3	b, c, e, g	50.64 (2.33)
Tychem SL	a, b, c ,d, e, f	61.29 (2.98)

*This item is significantly different from:
a: U.S. Army ACU
b: Blauer WZ9430 MIRT
c: Blauer WZ9435 XRT
d: Gentex Rampart
e: Lion MT94
f: Remploy SR3
g: Tychem SL
Note: Values are in A-weighted decibels.

Table 9. Mean Peak SPL for the Repeated Scan Movement

Suit	Comparison Key*	Mean (SD)
Baseline	b, c, e, f, g	34.72 (2.89)
Blauer WZ9430 MIRT	a, d, g	42.93 (1.45)
Blauer WZ9435 XRT	a, d, g	43.50 (2.54)
Gentex Rampart	b, c, e, g	37.73 (4.97)
Lion MT94	a, d, f	45.44 (2.22)
Remploy SR3	a, e, g	40.56 (3.05)
Tychem SL	a, b, c, d, f	47.82 (1.87)

*This item is significantly different from:
a: U.S. Army ACU
b: Blauer WZ9430 MIRT
c: Blauer WZ9435 XRT
d: Gentex Rampart
e: Lion MT94
f: Remploy SR3
g: Tychem SL
Note: Values are in A-weighted decibels.

3.3 Respiratory Protection Systems

Descriptive statistics were calculated for each respiratory protection system variable that was evaluated during this effort. The tables in this section list the mean peak SPLs for each APR, PAPR, and SCBA system when this equipment was worn with the Gentex Rampart suit. The Gentex Rampart suit was observed to be the quietest suit assessed during this effort and, in turn, allowed for the most sensitive comparison between the respiratory protection variables. Due to logistical challenges, only one volunteer wore the Scott Air-Pak SCBA; therefore, only descriptive statistics were assessed for this variable.

Tables 10–13 provide the mean peak SPLs for each of the respiratory protection variables when volunteers performed each of the LE movement scenarios. In addition to descriptive statistics, a one-way, repeated-measures, ANOVA on ranks was performed. The ANOVA on ranks was used because the data for each of the LE movement scenarios were not normal. For the simulated door entry and quick movement scenarios, evaluation of the ANOVA on ranks showed that significant differences existed between the respiratory protection variables. A Tukey multiple pairwise comparison test was used to determine the specific statistically significant differences between the respiratory protection system variables. These differences are provided in Tables 10 and 13. For the high-knee raise, scan-and-crouch, and rifle-scan movements, evaluation of the ANOVA on ranks did not indicate significant differences between the respiratory protection variables.

Table 10. Respiratory Protection System Comparison for Simulated Door Entry Movement

Respiratory System	No Mask Control (dBA)	Scott AV3000	Avon FM53	Scott 420 PAPR	Avon ST-PAPR	Avon ST53 SCBA	Scott Air-Pak SCBA
Mean (SD)	41.71 (3.31)	42.53 (2.49)	45.38 (4.58)	47.86 (0.90)	47.64 (1.14)	46.08 (3.12)	51.88 (one volunteer)
Comparison Key*	d, e	d	n/a	b, a	a	n/a	n/a

*This item is significantly different from:
a: No mask control
b: Scott AV-3000 APR
c: Avon FM53 APR
d: Scott 420 PAPR
e: Avon ST-PAPR
f: Avon ST53 SCBA
Note: Values are in A-weighted decibels.
n/a: not applicable

Table 11. Respiratory Protection System Comparison for High-Knee Raise and Scan Movement

Respiratory System	No Mask Control	Scott AV3000	Avon FM53	Scott 420 PAPR	Avon ST-PAPR	Avon ST53 SCBA	Scott Air-Pak SCBA
Mean (SD)	47.62 (6.80)	45.89 (3.57)	48.03 (5.59)	50.08 (4.06)	50.11 (3.38)	48.28 (3.70)	54.18 (one volunteer)

Note: Values are in A-weighted decibels.

Table 12. Respiratory Protection System Comparison for Crouch and Rifle-Scan Movement

Respiratory System	No Mask Control	Scott AV3000	Avon FM53	Scott 420 PAPR	Avon ST-PAPR	Avon ST53 SCBA	Scott Air-Pak SCBA
Mean (SD)	44.33 (6.06)	45.02 (3.92)	43.42 (1.79)	47.06 (1.28)	48.81 (1.69)	47.58 (2.71)	54.42 (one volunteer)

Note: Values are in A-weighted decibels.

Table 13. Respiratory Protection System Comparison for Quick Movement

Respiratory System	No Mask Control	Scott AV3000	Avon FM53	Scott 420 PAPR	Avon ST-PAPR	Avon ST53 SCBA	Scott Air-Pak SCBA
Mean (SD)	46.39 (4.53)	45.83 (2.30)	44.32 (1.92)	48.56 (0.91)	47.82 (1.29)	46.55 (3.28)	49.79 (one volunteer)
Comparison Key*	n/a	n/a	d	c	n/a	n/a	n/a

*This item is significantly different from:
a: No mask control
b: Scott AV-3000 APR
c: Avon FM53 APR
d: Scott 420 PAPR
e: Avon ST-PAPR
f: Avon ST53 SCBA
Note: Values are in A-weighted decibels.
n/a: not applicable

3.4 Drop-and-Crawl Exercise

A cursory comparison was performed between the LE movement scenarios and a replication of the audible signature test movement that was suggested in NIJ Standard-0116.00. Table 14 provides descriptive statistics related to this comparison. For all PPE conditions evaluated, the peak SPL created by the one volunteer performing the crawling motion was observed to be louder than the mean peak SPL for the LE movement scenarios chosen for this research effort. Once more, only seven PPE conditions were used for this comparison. These conditions were the baseline condition (i.e., Table 1; condition 1) and the conditions during which the FM53 APR was worn with each of the six suits (i.e., Table 1; conditions 3, 10, 14, 18, 22, and 26).

Table 14. PPE Condition and Movement Comparison

PPE Condition	Movement				
	Door Entry	High-Knee Raise and Scan	Crouch and Rifle Scan	Quick Movement	NIJ Standard Crawl
	Mean (SD)				Mean
Baseline without respirator	42.16 (3.99)	45.70 (6.16)	43.08 (5.30)	43.39 (3.67)	56.83
Blauer WZ9430 with FM53 APR	48.71 (2.49)	54.61 (3.14)	48.94 (2.71)	50.08 (2.59)	55.40
Blauer WZ9435 XRT with FM53 APR	51.45 (3.12)	56.43 (3.02)	52.18 (3.13)	55.79 (5.02)	60.88
Gentex Rampart with FM53 APR	45.38 (4.58)	48.03 (5.59)	43.42 (1.79)	44.32 (1.92)	60.57
Lion MT94 with FM53 APR	49.89 (2.11)	54.74 (1.91)	50.25 (2.19)	51.10 (2.60)	60.85
Remploy SR3 with FM53 APR	46.05 (4.85)	49.95 (3.50)	46.74 (3.40)	48.63 (4.47)	63.86
Tychem SL with FM53 APR	52.09 (2.25)	60.23 (2.40)	53.52 (2.57)	56.02 (3.35)	63.57

Note: Values are in A-weighted decibels.

4. DISCUSSION

4.1 LE Movement Scenarios

The Tychem SL and Blauer WZ9435 XRT suits were made of subjectively noisy fabrics and, for many LE movement and respiratory protection variable combinations, were observed to be significantly louder than the ACU baseline, Gentex Rampart, and Remploy SR3 suits. Although the Blauer WZ9430 MIRT and Lion MT94 suits also employed subjectively noisy fabrics, the differences in audible signatures for many LE movement and respiratory protection variable combinations were statistically insignificant when compared with the quieter suits.

4.2 Repeated Movements

Mean peak SPLs during the repeated rifle scan exercise were lower than those for the lunging exercise. Of the three repeated movements, the high-knee raise movement had the highest mean peak SPLs for each condition tested. As listed in Table 15, the ranking of quietest to loudest suit condition was the same for the crouch and high-knee raise movements. The results for the Blauer WZ9435XRT and Lion MT94 suits switched positions in the ranking during the rifle scan movement, but the rankings were otherwise the same as the crouch and knee-raise movements. For the large majority of repeated movement trials, the baseline, Gentex Rampart, and Remploy SR3 ensembles were observed to be significantly quieter than the other four suits.

Table 15. Quietest to Loudest Suit Type Ranking for the Repeated Movements

Noise Level Ranking	Repeated Movements		
	Crouch	Knee Raise	Scan
Quietest Suit	Baseline	Baseline	Baseline
↓	Gentex Rampart	Gentex Rampart	Gentex Rampart
↓	Remploy SR3	Remploy SR3	Remploy SR3
↓	Blauer WZ9430 MIRT	Blauer WZ9430 MIRT	Blauer WZ9430 MIRT
↓	Lion MT94	Lion MT94	Blauer WZ9435 XRT
↓	Blauer WZ9435 XRT	Blauer WZ9435 XRT	Lion MT94
Loudest Suit	Tychem SL	Tychem SL	Tychem SL

The individual volunteer data were also examined. For all volunteers and all suit conditions, the repeated rifle scan movement had the lowest peak noise levels of the three repeated movements. The high-knee raise movement was louder than the crouch movement for 48 of the 56 trials (8 volunteers and 7 conditions). Performing the high-knee raises repeatedly would create the overall loudest noise for the three repeated movements tested. Volunteers performing a series of alternating crouches and high-knee raises would likely encompass the worst-case scenario for noise creation.

4.3 Respiratory Protection Systems

In the study of respiratory protection system variables, PAPRs were found to have the greatest impact on the audible signature. Although the ST53 SCBA system did create an increase in noise when compared with the APR and no-mask conditions, the increase created by the PAPR variables was greater. Only the PAPR variables were shown to be significantly louder than the no-mask or APR variables. For the louder suit variables, the inclusion of respiratory protection had minimal to no impact on audible signature.

Additional trials with the Scott Air-Pak system would be needed to fully assess its impact on audible signature. However, data from the performance of one set of trials indicated that the Scott Air-Pak system's audible signature was greater than that of the ST53 SCBA and two PAPR systems evaluated.

4.4 Drop-and-Crawl Exercise

The sound levels recorded for the drop-and-crawl exercise, performed as prescribed in NIJ Standard 0116.00 (NIJ Crawl), were louder than those recorded during each of the four movement scenarios used for all of the seven PPE conditions tested. NIJ Standard 0116.00 contains recommended audible signature limitations of 45 and 55 dBA depending upon the level of protection the PPE ensemble provides. The NIJ crawl exercise produced sound levels greater than 55 dBA for each PPE condition tested. Because only one volunteer performed this movement, the data during those trials were also compared to the maximum peak SPLs for each suit condition, regardless of volunteer number or exercise movement scenario. These data are shown in Table 16.

Table 16. Maximum SPL and NIJ Crawl Exercise Comparison

Condition Number*	PPE Condition	NIJ Crawl (dBA)	Maximum SPL (dBA)
1	Baseline without respirator	56.8	56.3
3	Gentex Rampart with FM53 APR	60.6	56.4
10	Lion MT94 with FM53 APR	60.8	57.1
14	Remploy SR3 with FM53 APR	63.9	55.3
18	Blauer WZ9435 XRT with FM53 APR	60.9	61.4
22	Tychem SL with FM53 APR	63.6	63.5
26	Blauer WZ9430 MIRT with FM53 APR	55.4	58.5

*Condition numbers are listed in Table 1.

For conditions 18 and 26 (Table 1), at least one of the volunteers performing the exercises in the main study produced a peak noise level exceeding that of the NIJ crawl movement. During testing of conditions 1, 18, and 22 (Table 1), the peak sound levels produced with the drop-and-crawl exercise differed from the maximum SPL by 0.5, 0.5, and 0.1 dBA, respectively. To investigate further, the NIJ crawl data for each volunteer were compared to the same trials during the main study. For each trial, regardless of the movement scenario employed, the NIJ crawl exercise produced higher peak noise levels.

Table 17. NIJ Crawl and LE Movement Scenario Comparison

Condition Number*	PPE Condition	NIJ Crawl (dBA)	LE Movement			
			Door Entry (dBA)	High-Knee Raise and Scan (dBA)	Crouch and Rifle Scan (dBA)	Quick Movement (dBA)
1	Baseline without respirator	56.8	49.7	52.0	50.6	47.0
26	Blauer WZ9430 MIRT with FM53 APR	55.4	49.3	55.6	49.6	49.1
18	Blauer WZ9435 XRT with FM53 APR	60.9	47.4	54.7	51.3	58.1
3	Gentex Rampart with FM53 APR	60.6	53.8	50.7	45.8	45.3
10	Lion MT94 with FM53 APR	60.8	49.2	54.5	45.5	50.4
14	Remploy SR3 with FM53 APR	63.9	42.1	47.2	45.9	47.2
22	Tychem SL with FM53 APR	63.6	50.8	55.9	54.8	53.0

*Condition numbers are listed in Table 1.

These results indicate that the NIJ crawl exercise created higher sound levels than the individual LE movement scenarios that were investigated in this research effort. Additionally, the ranking of the quietest to loudest PPE conditions was different for the NIJ

crawl exercise and the four LE movement scenarios. Further analysis of the sound files for the NIJ crawl exercise may provide an indication of which portion of the crawling movement created the most noise. It was unknown whether the movement of the suit itself or the person contacting the ground created the loudest noise. In addition, an APR was worn during the NIJ crawl exercise trials, which may have impacted the results. Although the results from other movements studied herein indicated that the APR did not have an impact on audible signature, it was possible that the respirator or filter canister contacted the ground during the crawl and potentially affected the results. In addition to the fact that the NIJ crawl exercise created the loudest noise, the operational relevance of crawling in a potentially chemical- or biological-contaminated environment also requires further consideration.

5. CONCLUSIONS AND RECOMMENDATIONS

Fabric-based suits that use carbon as an adsorbent layer (i.e., Gentex Rampart, Remploy SR3) were generally found to be quieter than those that employed barrier materials of varied permeability (e.g. Tychem SL, Blauer 9435 XRT). Barrier materials tend to be noisier due to their stiffness, reduced drape, and lower mass when compared with carbon adsorbent layers.[7]

A further assessment of the impact of multiple respiratory protection systems on audible signature is needed. While APRs showed little to no increase in audible signature, PAPR and SCBA systems demonstrated the potential to generate a significant increase in PPE-generated noise, particularly when coupled with quieter suit fabrics. The noise-generation characteristics of most National Institute for Occupational Safety and Health CBRN-approved PAPR and SCBA respiratory protection systems have not been documented.

Additionally, a further assessment of the NIJ crawl exercise with a larger sample size of volunteers would be required to fully assess the differences between this NIJ-prescribed movement and the movements used during this study. To appropriately compare the audible signatures created during this study to the limitations set forth for CBRN PPE in NIJ Standard 0116.00, these movements would need to be replicated in a hemi-anechoic chamber that would enable compliance with the larger movement areas and microphone distances that are suggested in the standard.

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Blank

ACRONYMS AND ABBREVIATIONS

ACU	U.S. Army Combat Uniform
ANOVA	analysis of variance
APG	Aberdeen Proving Ground, MD
APR	air-purifying respirator
CBRN	chemical, biological, radiological, and nuclear
CC-TV	closed-circuit television
dBA	decibel A-weighting
ECBC	U.S. Army Edgewood Chemical Biological Center
LE	law enforcement
MIRT	major incident response team
n/a	not applicable
NFPA	National Fire Protection Association
NIJ	National Institute of Justice
NIJ crawl	drop-and-crawl exercise performed as prescribed in NIJ Standard 0116.00
PAPR	powered air-purifying respirator
PPE	personal protective equipment
SCBA	self-contained breathing apparatus
SD	standard deviation
SPL	sound pressure level
SWAT	special weapons and tactics
XRT	extended response team


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